# METHODS FOR MITIGATING THE PRODUCTION OF WATER FROM SUBTERRANEAN FORMATIONS

## BACKGROUND OF THE INVENTION

[0001] The present invention relates to treatment operations in subterranean zones, and more particularly, to consolidation compositions and methods of using these consolidation compositions to mitigate water production from subterranean formations.

[0002] The production of water with oil and/or gas from wells constitutes a major problem and expense in the production of oil and gas. While oil and gas wells are usually completed in hydrocarbon producing zones, a water bearing zone may occasionally be present adjacent to the hydrocarbon producing zone. In some circumstances, the higher mobility of the water may allow it to flow into the hydrocarbon producing zone by way of, *inter alia*, natural fractures and high permeability streaks. In some circumstances, the ratio of water to hydrocarbons recovered may become sufficiently high that the cost of producing, separating, and disposing of the water may represent a significant economic loss.

[0003] One attempt to reduce the production of water has been to place viscous polymers into water and hydrocarbon producing formations so as to cause them to enter the water-producing zones within and adjacent to the formations such that they may cross-link therein. The cross-linking of the viscous polymers tends to produce stiff gels, which may eliminate, or at least reduce, the flow of water through the natural fractures and high permeability streaks in the formations. However, such methods have achieved varying degrees of success, as the lack of strength of some of the viscous polymers has often caused them to deteriorate over time, necessitating the performance of additional treatments. This problem is often exacerbated in high temperature reservoirs (*e.g.*, reservoirs having temperatures in excess of about 350°F), where the viscous polymers tend to degrade at a much faster rate.

## SUMMARY OF THE INVENTION

[0004] The present invention relates to treatment operations in subterranean zones, and more particularly, to consolidation compositions and methods of using these consolidation compositions to mitigate water production from subterranean formations.

[0005] An exemplary embodiment of a method of the present invention is a method of mitigating the production of water from a subterranean formation, comprising the steps of injecting a consolidation composition comprising a furan-based resin into an interval in the subterranean formation; and permitting the consolidation composition to cure to a desired level of strength therein.

[0006] Another exemplary embodiment of a method of the present invention is a method of fracturing a subterranean formation comprising the steps of: injecting a consolidation composition comprising a furan-based resin into a subterranean formation; and injecting a fracturing composition into the subterranean formation so as to create or extend at least one fracture therein, wherein the fracturing composition comprises a carrier fluid and a proppant material.

[0007] The features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of the preferred embodiments, which follows.

## DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0008] The present invention relates to treatment operations in subterranean zones, and more particularly, to consolidation compositions and methods of using these consolidation compositions to mitigate water production from subterranean formations

[0009] The consolidation compositions of the present invention generally comprise a furan-based resin. Optionally, other additives may be included, including, but not limited to, a silane coupling agent, a surfactant, a diluent, and the like.

[0010] The furan-based resin may comprise a variety of resins that further comprise furfuryl alcohol oligomer resin, or a derivative thereof. The furan-based resins used in the consolidation compositions of the present invention are capable of enduring temperatures well in excess of 350 °F without degrading. In certain exemplary embodiments, the furan-based resins are capable of enduring temperatures up to about 700 °F without degrading. Suitable furan-based resins include, but are not limited to, furfuryl alcohol resins, mixtures of furfuryl alcohol resins and aldehydes, and a mixture of furfuryl alcohol resins and phenolic resins. One example of a furan-based resin suitable comprises about 25% to about 45% of a furan-furfuraldehyde homopolymer by weight and about 55% to about 75% of a furfuryl alcohol monomer by weight. Another example of a furan-based resin suitable for use in the methods of the present invention is a phenol/phenol formaldehyde/furfuryl alcohol resin comprising from about 5% to about 30% phenol by weight, from about 40% to about 70% phenol formaldehyde by weight, from about 10% to about 40% furfuryl alcohol by weight.

[0011] Optionally, a silane coupling agent may be used in the consolidation compositions of the present invention, *inter alia*, to act as a mediator to help bond the furan-based resin to particulate surfaces of the subterranean formation. Examples of silane coupling agents that can be used include, but are not limited to, n-2-(aminoethyl)-3-aminopropyltrimethoxysilane, 3-glycidoxypropyltrimethoxysilane, and n-beta-(aminoethyl)-gamma-aminopropyl trimethoxysilane. Where used, the silane coupling agent used is included in an amount capable of sufficiently bonding the resin to the formation particulates. In some embodiments of the present invention, the silane coupling agent used is present in the consolidation composition in the range of from about 0.1% to about 5% by weight of the furan-based resin.

[0012] Optionally, a ductility imparting agent may be present in the consolidation compositions of the present invention, *inter alia*, to improve the furan-based resin's ability to endure changes in the subterranean environment (*e.g.*, cyclic stresses that may occur during times when a well bore is placed on production after having been shut-in, and the like). Examples of suitable ductility imparting agents include, but are not limited to, phthalate materials. In certain exemplary embodiments, the phthalate materials may relax the crosslinking in the cured furan-based resin. Examples of suitable phthalate materials include, but are not limited to, alkyl phthalates such as diethyl phthalate, butyl benzyl phthalate, and di-(2-ethylhexyl)phthalate. Where used in the consolidation compositions of the present invention, the ductility imparting agent may be present in an amount in the range of from about 0.1% to about 10% by weight of the furan-based resin.

[0013] Optionally, a surfactant may be present in the consolidation compositions of the present invention. A wide variety of surfactants may be used, including, but not limited to, ethoxylated nonyl phenol phosphate esters, mixtures of one or more cationic surfactants, and one or more non-ionic surfactants and alkyl phosphonate surfactants. The mixtures of one or more cationic and nonionic surfactants suitable for use in the present invention are described in U.S. Patent No. 6,311,773, the relevant disclosure of which is incorporated herein by reference. In certain exemplary embodiments, a $C_{12} - C_{22}$ alkyl phosphonate surfactant is used. Where used, the surfactant or surfactants may be included in the consolidation composition in an amount in the range of from about 0% to about 15% by weight of the furan-based resin.

[0014] Optionally, a diluent or liquid carrier fluid may be present in the consolidation compositions of the present invention, *inter alia*, to reduce the viscosity of the consolidation composition for ease of handling, mixing and transferring. It is within the ability of one skilled in the art, with the benefit of this disclosure, to determine if and how much diluent is needed to achieve a viscosity suitable to a particular subterranean environment. Any suitable diluent that is compatible with the furan-based resin and achieves the desired viscosity effects is suitable for use in the present invention. In certain exemplary embodiments of the present invention, the diluents used have high flash points (most preferably above about 125°F). Examples of liquid carrier fluids suitable for use in the present invention include, but are not limited to, 2-butoxy ethanol, butyl acetate, and furfuryl acetate. Where used, the diluent is present in the consolidation compositions of the present invention in an amount in the range of from about 1% to about 200% by weight of the furan-based resin.

[0015] Optionally, the consolidation compositions of the present invention may further comprise a curing agent, *inter alia*, to facilitate or accelerate curing of the furan-based resin at lower temperatures. The presence of a curing agent may be particularly useful in certain exemplary embodiments of the present invention where the consolidation compositions of the present invention are placed within subterranean formations having temperatures below about 250 F. Examples of suitable curing agents include, but are not limited to, organic or inorganic acids, such as, *inter alia*, maleic acid, fumaric acid, sodium bisulfate, phosphoric acid, sulfonic acid, alkyl benzene sulfonic acids such as toluene sulfonic acid and dodecyl benzene sulfonic acid, and combinations thereof. Where used in the consolidation compositions of the present invention, the curing agent may be present in an amount in the range of from about 0.01% to about 10% by weight of the furan-based resin. In certain exemplary embodiments, the curing agent may be present in the consolidation compositions an amount in the range of from about 1% to about 3% by weight of the furan-based resin.

[0016] Optionally, the consolidation compositions of the present invention may further comprise a filler material, *inter alia*, to fill voids, cavities, crevices, channels behind casing strings, or channels within the formation itself. Examples of suitable filler materials include, but are not limited to, microspheres, or silica sand having a particle size in the range of less than about 300 mesh.

[0017] Where the consolidation compositions of the present invention are used to isolate an interval in a subterranean formation, the interval to be treated may be isolated, for example, by placing a packer within a well bore in the formation, at a location above and/or below the interval. Optionally, the interval may be treated with a precursor fluid (for example, an aqueous brine having a high salt concentration and further comprising a cationic surfactant), *inter alia*, to help remove fines from pore spaces and enhance coating of the furan based resin onto the substrate surface of the formation. The consolidation composition is then injected into the subterranean formation at the desired interval, after which excess resin may be displaced out of the well bore. The interval is then shut in for a period of time sufficient to allow the consolidation composition to cure to a desired level of strength, thereby transforming the treated interval within the formation into a substantially impermeable barrier that mitigates water production. In certain exemplary embodiments of the present invention, the interval may be shut in for a period of time in the range of from about 6 hours to about 72 hours, during which the consolidation composition may cure. The time period will depend on factors such as, *inter alia*, the composition of the furan-based resin, the temperature of the interval in the subterranean formation, and the level of strength desired from the consolidation composition after it cures. One of ordinary skill in the art, with the benefit of this disclosure, will be able to identify the proper time period for curing of the consolidation composition for a particular application.

[0018] In addition to isolating water-producing intervals in a subterranean formation, in certain exemplary embodiments the consolidation compositions of the present invention also may be used to prevent gas migration or water channeling behind casing or pipes within a subterranean well bore. In certain exemplary embodiments, this may be accomplished by first isolating the region where undesirable channeling is occurring, then injecting and curing the consolidation compositions of the present invention to fill in such channels.

[0019] In another embodiment, the consolidation compositions of the present invention may be used in connection with subterranean fracturing operations, *inter alia*, to isolate a water-producing interval within the subterranean formation by placing the consolidation composition deep in the formation ahead of the proppant pack. Exemplary methods of fracturing are disclosed in U.S. Patents Nos. 5,944,106 and 6,070,664, the relevant disclosures of which are hereby incorporated herein by reference. Where used in a fracturing operation, the consolidation compositions of the present invention may be placed in the prepad fluid (*e.g.*, a fluid comprising neither a crosslinker nor proppant) or the pad fluid (*e.g.*, a crosslinked fluid comprising no proppant), ahead of the proppant pack.

[0020] An exemplary embodiment of a method of the present invention is a method of mitigating the production of water from a subterranean formation, comprising the steps of injecting a consolidation composition comprising a furan-based resin into an interval in the subterranean formation; and permitting the consolidation composition to cure to a desired level of strength therein. Additional steps may include isolating the interval; treating the interval with a precursor fluid; and displacing excess consolidation composition from the well bore.

[0021] Another example of a method of fracturing a subterranean formation comprising the steps of: injecting a consolidation composition comprising a furan-based resin into a subterranean formation; and injecting a fracturing composition into the subterranean formation so as to create or extend at least one fracture therein, wherein the fracturing composition comprises a carrier fluid and a proppant material.

[0022] Therefore, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those that are inherent therein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit of this invention as defined by the appended claims.